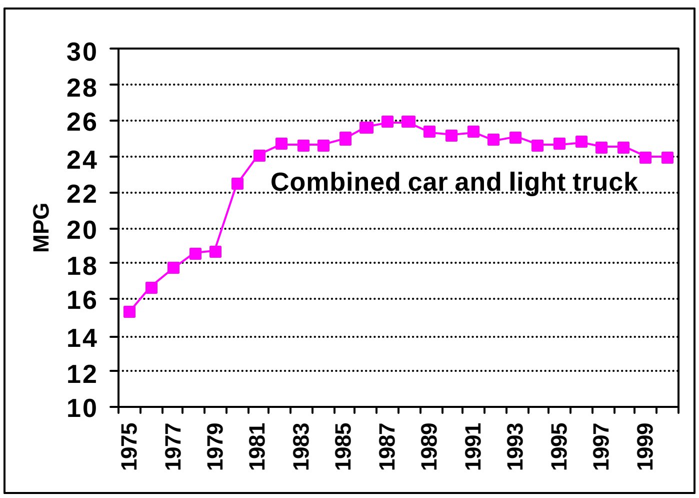
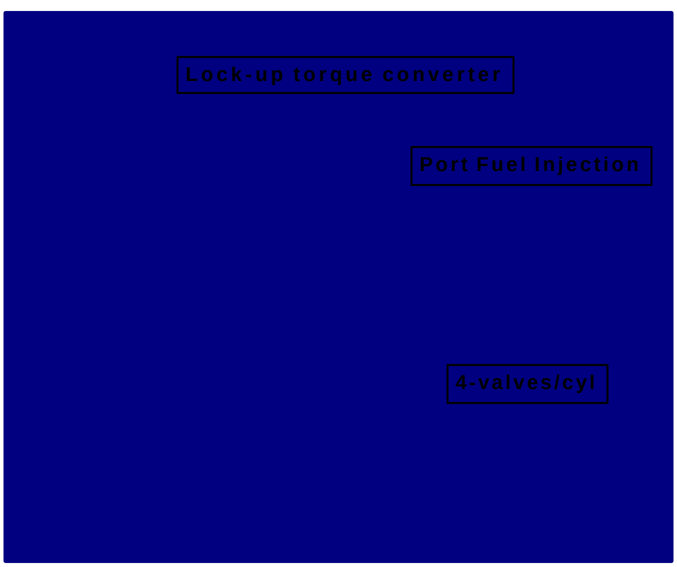
Good morning, my name is John German, Manager, Environment and Energy Analyses, Product Regulatory Office, American Honda Motor Co., Inc. Honda appreciates the opportunity to appear before the Senate Commerce, Science and Transportation Committee to discuss automotive fuel efficiency with a focus on technology.

The environmental challenge is one that Honda has long embraced. Honda products have always focused on the most efficient use of resources. It has been a part of Honda's culture from the beginning. To quote our founder, Mr. Honda, in 1974, "I cannot overstress the importance of continuing to cope with the pollution problem." We believe that we must think about more than just the products we make. We think about the people who use them and the world in which we live. We believe that it is our responsibility, as a manufacturer of these products, to do all we can to reduce the pollutants that are created from the use of products that we produce.

Conventional Technology

Figure 1

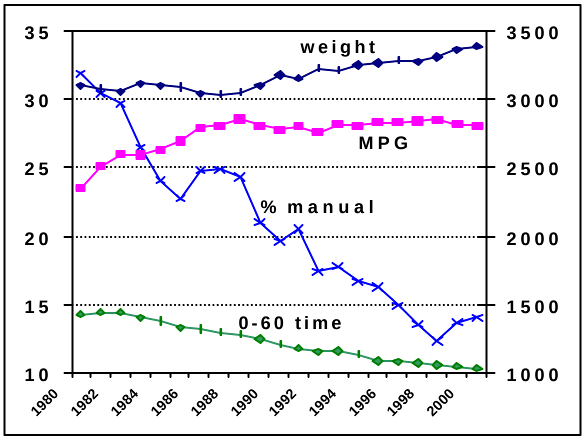


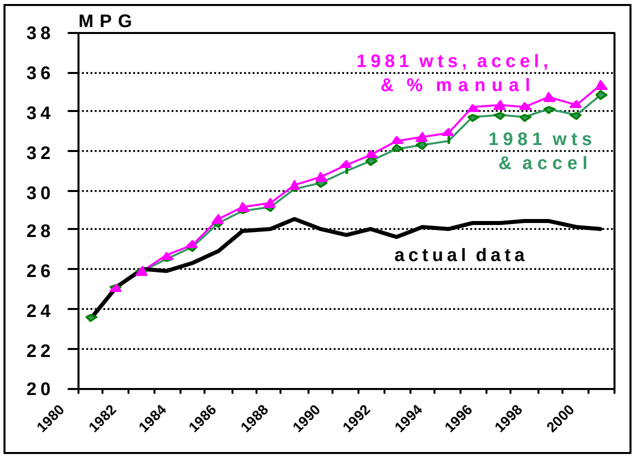


There is a popular misconception that vehicle manufacturers have not introduced fuel efficient technology since the mid-80s. This is understandable, as the car and light truck CAFE have remained constant for the last 15 years (and the combined fleet has gone down due to increasing light truck market penetration), as shown in Figure 1. However, there has been a substantial amount of efficiency technology introduced in this time period. Some examples for the entire car and light truck fleet from EPA's 2000 Fuel Economy Trends are shown in Figure 2.

However, this new technology has been employed more to respond to vehicle attributes demanded by the marketplace than to increase fuel economy. Over the past two decades consumers have insisted on such features as enhanced performance, luxury, utility, and safety, without decreasing fuel economy. Figure 3 shows the changes in vehicle weight, performance, and proportion of automatic transmissions since 1980 in the passenger car fleet. Even though weight increased by 12% from 1987 to 2000, the 0-60 time decreased by 22% from 1981 to 2000. This is because average horsepower increased by over 70% from 1982 (99 hp) to 2000 (170 hp). In addition, the proportion of manual transmissions, which are much more fuel efficient than automatic transmissions, decreased from 32% in 1980 to 14% in 2000.

It is clear that technology has been used for vehicle attributes which consumers have demanded or value more highly than fuel economy. Figure 4 compares the actual fuel economy for cars to what the fuel economy would have been if the technology were used solely for fuel economy instead of performance and other attributes. If the current car fleet were still at 1981 performance, weight, and transmission levels, the passenger car CAFE would be almost 36 mpg instead of the current level of 28.1 mpg. The trend is particularly pronounced since 1987. From 1987 to 2000, technology has gone into the fleet at a rate that could have improved fuel economy by about 1.5% per year, if it had not gone to other attributes demanded by the marketplace.





There is no reason why this technology trend of improved efficiency (as opposed to fuel economy) should not continue. Many of the technologies in the 2000 fleet, such as 4-valve per cylinder, have not yet spread throughout the entire fleet (although Honda vehicles have been virtually 100% 4-valve per cylinder since 1988). In addition, several new technologies that will have significant efficiency benefits are just beginning to penetrate the fleet. One technology pioneered by Honda is variable valve timing. While Honda used variable valve timing in almost 60% of our 2000 vehicles, penetration in the other manufacturers' fleets is only a percent or two. Other technologies that have recently been introduced or for which at least one manufacturer has announced plans to introduce include:

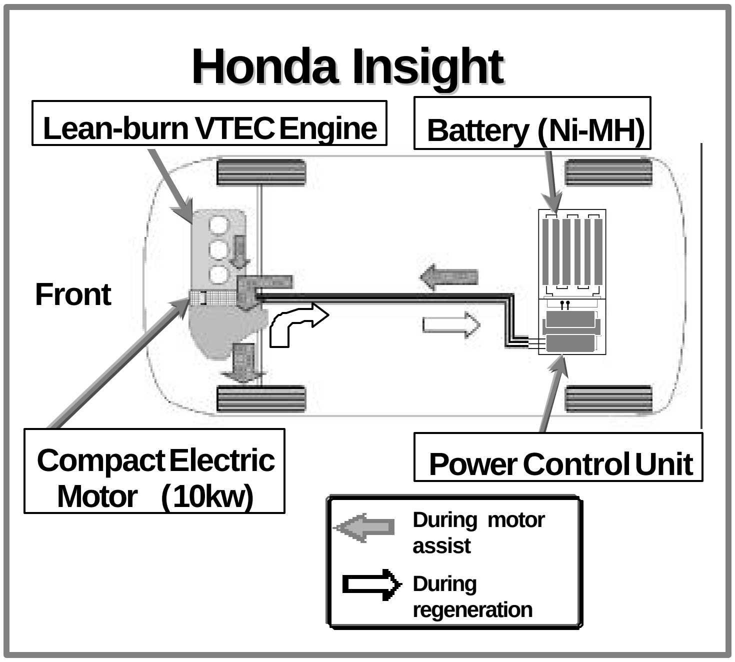
- Direct injection gasoline engines (only announced for Europe and Japan to date)
- 5-speed automatic and 6-speed manual transmissions
- Continuously variable transmissions (works like an automatic, but more efficient)
- Lightweight materials
- Low rolling resistance tires
- Improved aerodynamics
- Cylinder cut-off during light-load operation (for example, an 8-cylinder engine shuts off 4 cylinders during cruise conditions)
- Idle-off (the engine stops at idle)

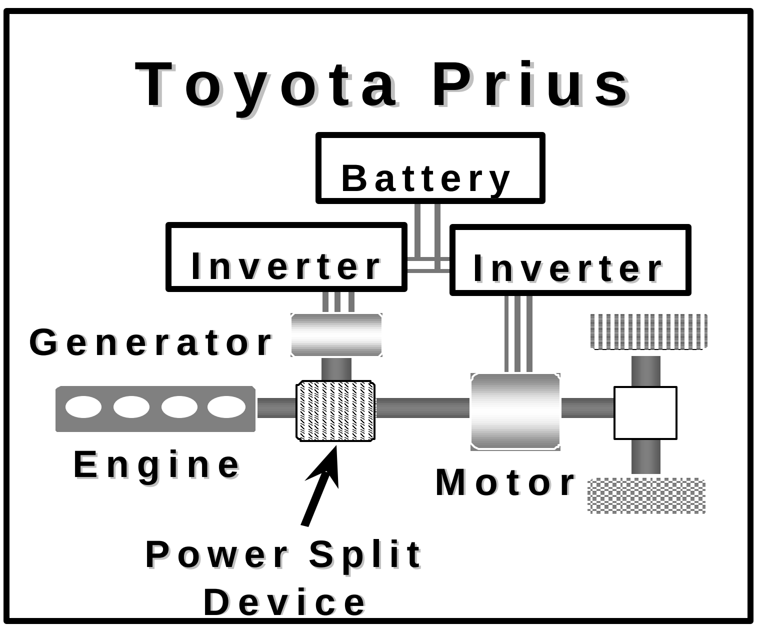
Technologies are continuously being incorporated into vehicles. However, consumer’s sense of value usually puts fuel efficiency near the bottom of their list. The dilemma facing manufacturers is that customers may not value putting in these technologies just to improve fuel economy.

Gasoline-Electric Hybrids

The competitive technologies that I have just described will be integrated in vehicle fleets in the relative near term. The most promising technology on the mid-term horizon (5-15 years) are hybrid vehicles – vehicles which employ two power sources. The two hybrid vehicles recently introduced in the US, the

Honda Insight and the Toyota Prius, both use innovative hybrid techniques. There are some basic operating characteristics that help shape the design of any hybrid system. The greatest demands on horsepower and torque occur while accelerating and climbing grades. Minimal power is needed to maintain a vehicle's speed while cruising on a level road. By using an electric motor to provide a power boost to the engine when appropriate, a smaller, more fuel-efficient gasoline engine can be used. In addition, the motor can be used to capture energy that would normally be lost during deceleration and braking and use this energy to recharge the battery. This process is referred to as "regenerative braking". These vehicles do not need to be plugged in. Finally, the powerful electric motor can restart the engine far quicker than a conventional starter motor and with minimal emission impact, allowing the engine to be shut off at idle.





Honda's Integrated Motor Assist (IMA) relies primarily on a small gasoline motor and is supplemented by a high torque, high efficiency DC brushless motor located between the engine and the transmission[1]. This 10 kW motor is only 60 mm (2.4") thick and is connected directly to the engine's crankshaft. It supplies up to 36 ft-lb. of torque during acceleration and acts as a generator during deceleration to recharge the battery pack. This is a simple, elegant method to package a parallel hybrid system and minimizes the weight increase.

Toyota's hybrid system combines both series and parallel systems.[2] The Prius powertrain is based on the parallel type. However, to optimize the engine's operation point, it allows series-like operation with a separate generator.

Both models use relatively small battery packs. The Insight's NiMH battery pack is rated at about 1 kW-hr of storage and only weighs about 22 kg (48 pounds). The battery pack on the Prius is larger, but is still

[1] "Development of Integrated Motor Assist Hybrid System", K. Aoki et al, Honda, June, 2000, SAE paper # 2000-01-2059

[2] Prius information is based upon October, 1999 Presentation by Dave Hermance of Toyota, "Toyota Hybrid System Concept and Technologies"

no more than twice the size of the Insight's. These lightweight battery packs help to maintain in-use performance and efficiency while maintaining most of the hybrid system benefits. The larger motor and battery on the Prius also allow limited acceleration and cruise at light loads on electricity only.

Both the Insight and the Prius incorporate substantial engine efficiency improvements, in addition to the downsizing allowed by the hybrid system. The Prius uses a low friction, Atkinson cycle 1.5L engine. The Atkinson cycle uses a longer expansion stroke to extract more energy from the combustion process to boost efficiency.

The Insight engine incorporates a number of different strategies to improve efficiency. The engine has Honda's variable valve technology, which boosts peak horsepower and allows even more engine downsizing. The 1.0L, 3-cylinder engine also incorporates lean-burn operation, low friction, and lightweight technologies to maximize fuel efficiency. Despite the small engine size, the Insight can sustain good performance with a depleted battery, due to the high power/weight from the VTEC engine.

What is especially interesting about the Insight and Prius comparison is that very different powertrain technologies were used to achieve similar efficiency goals. One important lesson is that the different types of hybrid systems have reasonably similar environmental performance. The new continuously variable transmission (CVT) Insight is rated as a SULEV. There are an infinite number of ways to combine hybrid components to create a practical hybrid electric vehicle.

Both the Insight and the Prius have achieved impressive fuel economy improvements. The manual transmission Insight has the highest fuel economy label values ever for a gasoline vehicle, 61 mpg city and 68 highway. The CVT Insight is rated at a slightly lower level. While much of the high fuel efficiency is attributable to the hybrid engine, other fuel efficient technologies, such as aerodynamic design and strategic use of lightweight materials were incorporated into the Insight as well. The Prius values are 52 mpg city and 45 highway.

Projections have also been made for prototype or future hybrid designs. Table 1 compares the manufacturer claims for the prototype vehicles to the production values for the Insight and Prius. It should be noted that Table 1 presents CAFE values, instead of fuel economy label values.[3]

Table 1: Hybrid Vehicle Comparison

		CAFE mpg	% improvement**
Commercial	Honda Insight	76	91%
Commercial	Toyota Prius	58	50%
Prototype	Ford Escape SUV	40	40-70%
Prototype	Dodge Durango SUV	19	20%
Prototype	GM SUV	35	20%
Prototype	GM full-size pickup	20	15%
Prototype	Ford Prodigy – PNGV diesel	70*	155%
Prototype	DC ESX3 – PNGV diesel	72*	162%
Prototype	GM Precept – PNGV diesel	80*	191%

* Gasoline-equivalent mpg

** Baseline for Escape is 24 mpg (V6) to 29 mpg (4-cyl)
Baseline for PNGV is 28 mpg (based on typical midsize car)

[3] EPA discounts the city test by 10% and the highway by 22% when calculating fuel economy values, so the combined FE based upon the label values discussed in the last paragragh is about 15% lower than the CAFE values in Table 1.

While it is easy to overlook because of the large efficiency benefits, hybrids also offer some potential emission reductions. The lower fuel consumption directly reduces upstream emissions from gasoline production and distribution. If the higher efficiency is used to increase range, evaporative emissions from refueling are reduced.

Future potential for hybrid powerplant applications and volume sales

Hybrids have a number of positive features that are desired by customers. They use gasoline (or diesel fuel); thus there are no concerns about creating a new infrastructure to support fueling. The customer benefits from lower fuel costs, extended range, and fewer trips to the gas station. Hybrids have good synergy with other fuel economy technologies and even help reduce emissions. Equally important, there is little impact on how the vehicle operates. The vehicles drive and operate similar to conventional vehicles.

Recent announcements from a number of manufacturers indicate that hybrid systems are being considered across a very broad vehicle spectrum. Toyota has announced production of a hybrid electric minivan for the Japanese market.[4] Honda recently announced a hybrid version of the Civic 4-door sedan that will be sold in the US beginning in spring 2002. Ford has announced plans to put a hybrid system into a 2003 model year Escape, a small SUV.[5] DaimlerChrysler will offer a hybrid in its Durango SUV sometime in 2003.[6] General Motors is already selling hybrid bus systems and plans to sell hybrid versions of its full-size pickup truck and the forthcoming Saturn VUE SUV in 2004.[7] There appears to be no inherent limitation on the use of hybrid systems, as long as packaging, weight, and cost issues can be managed.

While there have been tremendous strides in hybrid technology, there remain some packaging issues such as finding space for the motor, battery pack, and power electronics, as well as some additional weight. However, these issues are secondary compared to the cost issue.

Unfortunately, hybrid systems are not cheap. Manufacturers are understandably reluctant to discuss the cost of their hybrid systems, so it is difficult to determine a realistic cost. Initially, hybrids also have high development costs spread over relatively low sales. DaimlerChrysler has said the hybrid Durango will cost about $3000 more than the standard model.[8] Peugeot-Citroen recently stated that they "…have set a target of making the cost of stepping up to hybrid power no greater than the amount motorists are now prepared to pay for the switch from petrol to diesel."[9] Ford stated that the hybrid is expected to add about $3000 to the price of the Escape[10], although it should be noted that a Ford engineer recently stated that the $3000 price increment will not cover all of their costs.[11]

To put the cost issue into context, let's take a look at what customers might be willing to pay in exchange for the fuel savings, both in the US and overseas. To do this, we need to make a few assumptions. The most critical is customer discounting of fuel savings. It is generally understood that most customers in the US only consider the first four years of fuel savings, plus they heavily discount even these four years. This is roughly equivalent to assuming that customers only value the fuel savings from the first 50,000 miles. For lack of information, the same 50,000 mile assumption is used for overseas customers (who drive less per year but may value the fuel savings more).

[4] "Toyota sees a hybrid future", Autoweek, October 30, 2000
[5] Ford Motor Co. press releases, January 10, 2000 and April 7, 2000
[6] Associated Press article by Justin Hyde, October 25, 2000
[7] General Motors Co. press release, January 9, 2001
[8] Associated Press article by Justin Hyde, October 25, 2000
[9] Parallel hybrid project director Emmanuel Combes of PSA in August, 2000 issue of Global Automotive Network.
[10] Ford Motor Co. press release, January 10, 2000
[11] Ford Escape Chief Engineer, comments during May 18, 2001 edition of PBS Science Friday

Estimates were made for three different size vehicles, small cars, midsize cars, and large trucks. Three estimates were also made for the hybrid benefits, as the improvements listed in Table 2 range from 15% to 196%. Of course, most of the vehicles in Table 1 include factors that go well beyond the impact of the hybrid system itself, such as weight and load reduction, engine efficiency improvements, and dieselization. A reasonable factor for just the hybrid system and corresponding engine size reduction is probably about 30-40% over combined cycles. Sensitivity cases of 20% (for very mild hybrids) and 80% (for hybrids combined with moderate engine and load improvements) are also shown in Table 2.

The final factor is fuel cost. Table 2 lists two cases: \$1.50/gallon (US) and \$4.00/gallon (Europe and Japan). The formula used to calculate the fuel savings in Table 2 is:

$$\left(\frac{50{,}000 \text{ miles}}{\text{baseline mpg}} - \frac{50{,}000 \text{ miles}}{\text{base mpg}*(1+\text{FE inc.})} \right) * \text{ Fuel cost}$$

Table 2: Customer Value of Hybrid Fuel Savings (savings for the first 50,000 miles)

		Small car	Midsize car	Large truck
FE increase	Fuel cost	40 mpg	27 mpg	16 mpg
20%	$1.50/gal	$313	$463	$781
	$4.00/gal	$833	$1,235	$2,083
40%	**$1.50/gal**	**$536**	**$794**	**$1,339**
	$4.00/gal	**$1,429**	**$2,116**	**$3,571**
80%	$1.50/gal	$833	$1,235	$2.083
	$4.00/gal	$2,222	$3,292	$5,556

The results are sobering. From a **societal** view, the fuel savings over the full life of the vehicle (which are about three times the values in Table 2), would likely justify the approximately $3000 cost of hybrid systems. However, the typical **customer** would not make up the incremental cost of $3000 by the fuel savings, especially in the US. In Japan and Europe, there may be a substantial market for hybrids even at a cost of $3000, due to the higher fuel prices. If the hybrid cost could be reduced to $1500 or $2000, the majority of customers in Japan and Europe might be willing to purchase a hybrid vehicle.

Even in the US, there are customers who, because they drive a lot or value the benefits more highly, will be willing to pay a $3000 premium for a hybrid vehicle. However, it is clear that hybrids will not break into the mainstream market in the US unless the cost of hybrid systems comes down and/or some sort of market assistance or incentive program is adopted.

Over the next five to ten years, we are likely to see a gradual increase in hybrid sales in the US. While the approximately $3000 cost increment in 2003 is too high for the mass market in the US, enough customers will desire the features to keep the market growing. In addition, hybrid sales are likely to increase much faster in Europe and Japan, due to their much higher fuel costs. This will lead to higher volume production and further development, both of which will reduce cost worldwide. Sales in the US will continue to increase as the costs come down.

But there is a broader message here for US policymakers. All of the technology improvements that can be made are incremental and have a financial cost. Absent marketplace signals as well, progress on achieving higher fuel efficiency in the marketplace may be slower than we may desire.

Fuel Cells

Fuel cells are the most promising mid- to long-term option. Hydrogen fuel cells have virtually no emissions and are extremely efficient. Large-scale production of hydrogen would probably use natural gas, which would reduce our dependence on fossil fuels. Even longer term, we may be able to produce hydrogen using solar energy or biomass fuels.

However, there remain a lot of issues to resolve before fuel cell vehicles become commercially viable. Cost and size must be drastically reduced and on-board hydrogen storage density must be significantly improved. Durability must also be proved. Even after all these problems are solved, there are still infrastructure issues for fueling systems to resolve. Thus, fuel cells will be a long time in development.

There also are some serious concerns about on-board reformers for creating hydrogen. Reformers are the hardware that converts fuel like natural gas or methane, to hydrogen. These reformers are expensive, take up valuable space in the vehicle, and are slow to warm up and respond to transient driving conditions. In addition, they reduce the efficiency of the vehicle, both because of the energy needed for the reforming process and because the resulting fuel stream is not pure hydrogen. The dilution of the fuel stream requires a larger fuel cell stack to maintain the same performance, increasing weight, size, and cost of the system. In fact, recent research has concluded that fuel cells with on-board reformers may not be more efficient than a good gasoline hybrid.[12]

Honda's current research efforts are focused on direct hydrogen fuel cell vehicles. These are not yet ready for the public, not ready for "numbers", not ready to help fill requirements for zero emission vehicles. There is much work to be done - our focus is to see if we can stimulate progress on R&D for hydrogen production ideas and toward infrastructure concepts and development. But even if all of the technological and infrastructure obstacles can be overcome, we are still one to two decades away from serious commercial introduction. However Honda is serious about this technology because it holds promise for environmentally sound transportation.

Electric Vehicles

While we are optimistic about the prospects of fuel cell vehicles, our experience with battery electric cars must serve as a warning. A decade ago, we all thought battery electric vehicles were the wave of the future. They promised emission-free, potentially renewable mobility with the performance of conventional internal combustion engines. So confident was California in the technology that the state required all major manufacturers to sell battery electric vehicles for 10% of their California sales.

Unfortunately, the battery technology did not evolve as we all had hoped or expected. Today's batteries – even the most sophisticated – are heavy, expensive (tens of thousands of dollars per vehicle at production levels), have poor capacity (100 miles at best) and take 3 to 8 hours to charge. Moreover, there is nothing on the horizon that will make these vehicles acceptable in the marketplace. While California stubbornly clings to the hope that battery EVs will evolve (although it will now require these vehicles to constitute 2% of sales) they simply will not meet our expectations as an alternative to the internal combustion engine. I offer this experience as a caution that policymakers cannot get too far ahead of the technology. Sometimes what we expect simply does not occur.

But there is also another lesson to be learned from our experience with electric vehicles. Market-forcing regulation should remain technologically neutral. California's zero emission vehicle mandate essentially

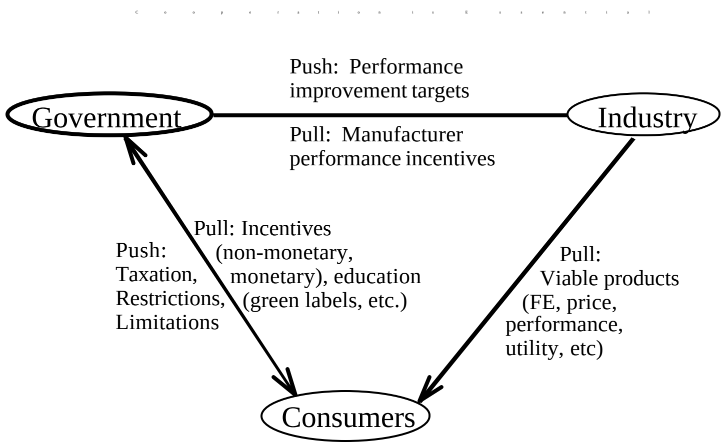
---

[12] "On the Road in 2020", M. Weiss, J. Heywood, E. Drake, A. Schafer, and F. AuYeung, Massachusetts Institute of Technology, October 2000.

requires manufacturers to sell electric vehicles – vehicles which very few consumers will want. In response to the California mandate, there will be a flood of golf cart type electric vehicles hitting the California market – which technically comply with the mandate but whose real contribution to air quality will be very mild at best. If there is to be regulation, it should be in the form of realistic performance standards which leave to the ingenuity of industry the opportunity to explore, develop or market technologies that are practical, perform as required and are economical.

Customer Preference

Honda believes it has a duty to be a responsible member of society and to help preserve the global environment. Honda is committed to contributing to mitigation of greenhouse gas emissions through technological progress. We believe it is our responsibility to develop and offer efficient products in the market. We have been an industry leader in introducing such products and will continue to do so.



However, unless the customer becomes an integral participant in the process of reducing greenhouse gases, market acceptance of these products will be limited. Programs will be far more effective if they include government and customers, not just industry. The industry can provide a "pull" by providing products desired by the consumer. But, we cannot push customers into buying vehicles they do not want. Government programs to stimulate demand, provide incentives, and educate the customer could dramatically affect acceptance of new technologies and market penetration.

Thank you for this opportunity to testify. I would pleased answer any questions you may have.